

# Le $J/\psi$ , sonde du plasma de quarks et gluons

blabla

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# Production du $J/\psi$

production de la paire de quarks  $c\bar{c}$   
production du quarkonia

# Caractéristiques des quarkonia

# Modification des fonctions de distributions de partons

# Modification des fonctions de distributions de partons

eps08

cgc

+ plot dAu

# Interaction avec le milieu

effet cronin

absorbtion nucléaire : alpha s

absorption par co-voyageurs

# Suppressions

effet cronin

absorption par les covoyageurs  
résultats du SPS

# Augmentation

coalescence

résultats SPS + HSD RHIC

Raa + diff mid/forward

# Plusieurs interprétations

Extrapolation des effets chauds Raa + extrapolation

Saturation de gluons

saturation+co-voyageurs

Recombinaison + dissociation

# Bilan

Quarkonia pas si simple que ça finalement  
plusieurs mécanismes en compétitions  
production complexe  
comment s'en sortir ?

# What is the elliptic flow ?

Azimuthal anisotropy emission of particles with respect to the collision reaction plane.

**Origin** : pressure gradient anisotropy in the overlapping zone of the two nuclei in non-central collisions.

A positive elliptic flow indicates a rapid thermalization of the probe with the system.

$v_2$

Quantified by the second Fourier coefficient of the azimuthal distribution of particles with respect to the reaction plane :

$$\frac{dN}{d(\phi-\psi)} = A[1 + 2.v_2 \cdot \cos 2(\phi - \psi)]$$

# Flot des hadrons légers

# Interprétations

saturation

recombinaison des quarks constituantes  
cascades partoniques

# Flots des mésons lourds

# Flot du quarks $c$

# Why are we interested in the $J/\psi$ elliptic flow ?

Electrons from open  $c$  and  $b$  semi-leptonic decays show positive flow.

Secondary  $J/\psi$ s produced by recombination mechanism should inherit  $c$  quarks' flow.

# Dispositif expérimental

$J/\psi \rightarrow \mu^+ \mu^- \quad |y| \in [1.2, 2.2]$

Muon identification : matching  
between track momentum and  
penetration depth in larroci tubes  
(MuID) + absorbers

Selection with front absorber

Momentum measured with cathode  
strip chambers (Mutr)

# Nombre de $J/\psi$

## Combined background subtraction

Combining mixed-event and like-sign distributions

Purpose :  $FG_{+-} - FG_{like} \cdot \frac{Mixed_{+-}}{Mixed_{like}}$

- mixed event distributions account for the acceptance bias
- like-sign distributions account for the bias introduced by the online filtering

Mixed-event subtraction      Combined subtraction

Normalisation + error] Nolrmalisaatoin + Error

Ajustement] Ajustement Acc times eff] Acc times eff  
Taux de production] Taux de production

## At forward rapidity

### Which RxnP detector ?

The muon arms and the RxnP acceptances overlap  
(RxnP :  $|\eta| \in [1, 2.8]$ , MuTr :  $|y| \in [1.2, 2.2]$ )

Might bias the measurement if the muons and possible produced particles by radiative gluons go through the RxnP detector used to estimate the reaction plane angle.

⇒ The RxnP detector opposite to the arm where the muons go is used in order to minimize the bias

# Measuring the elliptic flow

# Method

Estimate the ratio between the number of  $J/\psi$  going in-plane,  $N^{\text{in}}$ , and the number of  $J/\psi$  going out-plane,  $N^{\text{out}}$  :

$$v_2^{\text{meas}} = \frac{\pi}{4} \cdot \frac{(N^{\text{in}} - N^{\text{out}})}{(N^{\text{in}} + N^{\text{out}})}$$

$$\sigma_{v_2^{\text{meas}}} = \frac{\pi/2}{(N^{\text{in}} + N^{\text{out}})^2} \cdot \sqrt{(N^{\text{out}} \sigma^{\text{in}})^2 + (N^{\text{in}} \sigma^{\text{out}})^2}$$

with  $\sigma^{\text{in}}$  the error on  $N^{\text{in}}$  and  $\sigma^{\text{out}}$  the error on  $N^{\text{out}}$ .

$v_2^{\text{meas}}$  is then corrected by the reaction plane resolution.

The following bins have bin used :

in  $\phi\text{-}\psi$   $[0, \pi/4]$  and  $[\pi/4, \pi/2]$

# Data taking conditions

luminosité équivalente

## Equivalent number of minimum bias events :

South arm :  $3.41 \times 10^9$  events

North arm :  $3.88 \times 10^9$  events

⇒ almost four times more than published Au+Au results (Run-4).

## Level-2 filtered data

Online filtering based on fast tracking in the MuID

## Errors on $v_2$

### Bars : statistical and point to point uncorrelated errors

From the  $J/\psi$  signal extraction :

statistical uncertainty on the number of counts ;

systematic uncertainty on the signal + background line-shape.

### Boxes : point to point correlated errors

Error on the average RxnP detector resolution

Error on the  $J/\psi \phi$  angle measurement that is less accurate at  $p_T < 1$

### Written : global relative systematics

Error on the technique used to determine the reaction plane angle and resolution.

Relative error that allows points to move coherently by 3% of their value

# J/ $\psi$ $v_2$ at forward rapidity (each arm)

bars : uncorrelated point to point + statistics from signal extraction

boxes : systematics, correlated point to point

global error : relative, applied to each point

# J/ $\psi$ $v_2$ at forward (averaged over the 2 arms)

bars : uncorrelated point to point + statistics from signal extraction

boxes : systematics, correlated point to point

global error : relative, applied to each point

# Mesure au SPS

# J/ $\psi$ $v_2$ measured by PHENIX

Mid and forward rapidity results use different detectors, triggers, methods...

They are fully independent measurements.

Details on mid-rapidity  $v_2$  method in arXiv :0806.0475

# J/ $\psi$ $v_2$ measured by PHENIX

Predictions are for mid-rapidity and most of the time for centrality [0,100%].

$$\begin{array}{lll} p_T [0,5] & |y| \in [1.2, 2.2] & v_2 = -0.094 \pm 0.104 \pm^{0.004}_{0.004} \\ & |y| < 0.35 & v_2 = -0.10 \pm 0.10 \pm 0.02 \end{array}$$

# J/ $\psi$ $v_2$ measured by PHENIX

tibility of combined results with  $v_2 > 0$  is  
10%

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Combining points at  $p_T$  [1,2]GeV,  $v_2 > 0$  at 6.3%

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## Summary / perspective

### First measurement at forward rapidity

$$p_T \in [0, 5] \text{ GeV/c}, v_2 = -0.094 \pm 0.104^{+0.003}_{-0.004}$$

Current precision does not allow to draw any conclusion.

Data points are compatible with zero to maximum flow predictions within errors

### What to expect for final results ?

Minimum bias sample  $\Rightarrow$  slight improvement to expect :  
+10% stat and no more bias from the online filtering  
 $\sqrt{2}$  smaller statistical errors on the  $v_2$

However, will probably still not permit to discriminate between models. Much larger data sample is needed.

Next data at RHIC (2009, 2010) should give more statistics.

## Backups

# Signal fit

Gaussian with variable width and amplitude centered on the  $J/\psi$  mass + exponential to account for the physical residual background

Double gaussian fit with fixed width (estimated from p+p data) and variable amplitude centered on the  $J/\psi$  mass + exponential

Exponential fit to the residual background outside the  $J/\psi$  mass region + counting the number of entries above its extrapolation to the  $J/\psi$  range

## Statistical errors

Mean value of the 3 fits

## Systematics are estimated

using the 3 canonical fit functions to the signal ;

varying the fits mass range (starting from 1.5, 1.7, and 2 GeV) ;

changing of the normalisation using a correction factor of  $1 \pm 0.02$  to the second term of the signal equation.

The systematic error is the RMS of the resulting 27 values.

## $v_2$ simulations

### Chain :

Retreive the reaction plane  $\psi$  angle from real data (RD)

We retrieve the input  $v_2$  : here for

Generate randomly distributed  $J/\psi$  along  $f(x) = [0](1 + 2 \times 0.3 \times \cos(2x))$   
about the same amount of statistics  
used in real data to get a  $v_2 = 0.3$  with respect to the RD reaction plane angle, starting from  
 $J/\psi$ 's generated by PYTHIA.

This FULL GEANT Simulation + Embedding in the same RD + Reconstruction  
method (including online-filtering algorithm)

Run same  $v_2$  extraction macro

# Summing centrality bins

## Issue

Efficiency varies vs. centrality inside the bins that are considered

If we further divide the bins, the signal gets too small

## Method

Weight the unlike-sign mass distributions (foreground and background) in 5% centrality bins by  $1/\epsilon$  and sum over larger centrality bins before fitting the signal

$$N = \frac{\sum_i N_i / \epsilon_i}{\sum_i 1 / \epsilon_i} \quad (1)$$

This maximizes the signal to be fitted

# Averaging over North ( $y \geq 0$ ) and South ( $y \leq 0$ ) arms

$$\frac{dN_{J/\psi}^{\text{ave}}}{dy} = \frac{w_S dN_{J/\psi}^S/dy + w_N dN_{J/\psi}^N/dy}{w_S + w_N} \quad (2)$$

where  $dN_{J/\psi}^S/dy$  ( $dN_{J/\psi}^N/dy$ ) is the  $J/\psi$  invariant yield measured in south (north) muon arm

$w_S$  ( $w_N$ ) the corresponding weight :

$$w = 1/\sigma_{\text{arm, uncor}}^2 \quad (3)$$

The weight accounts for arm uncorrelated errors.

Here, these errors are the statistical and systematic errors on the signal fit.

This allows to reduce the statistical and systematic errors on the yields by  $\sqrt{2}$ .

*Note :* The correlated errors used to calculate the  $\text{acc} \times \text{eff}$  do not enter the weight factors. For the  $v_2$  analysis,  $\text{acc} \times \text{eff}$  cancels out since it always appear at the nominator and the denominator when used.

# Use of the RxnP detector

## Resolution

Use of Ollitrault function (arXiv :nucl-ex/9711003v2)

The resolution of the North and the South RxnP is found using MPC or BBC as third detectors.

## Averaging over centrality

Weight the RxnP resolution by the  $J/\psi$  counts corrected by the efficiency

# Calculating the reaction plane resolution

Measurement methods see Ollitrault (arXiv :nucl-ex/9711003v2) and Voloshin & Poskanzer (arXiv :nucl-ex/9805001v2)

If we wish to measure  $v_2$  with respect to the reaction plane we calculate :

$$\begin{aligned} v_2^{meas} &= \langle \cos 2(\phi - \psi_{meas}) \rangle \\ &= \langle \cos 2(\phi - \psi_{true} - \delta\psi) \rangle \\ &= \langle \cos 2(\phi - \psi_{true}) \cos 2(\delta\psi) - \sin 2(\phi - \psi_{true}) \sin 2(\delta\psi) \rangle \\ &= \langle \cos 2(\phi - \psi_{true}) \rangle \langle \cos 2(\psi_{meas} - \psi_{true}) \rangle \\ &= v_2^{true} \langle \cos 2(\psi_{meas} - \psi_{true}) \rangle \end{aligned}$$

Resolution

$$\langle \cos 2(\psi_a - \psi_b) \rangle = \langle \cos 2(\psi_a - \psi_{true}) \rangle \langle \cos 2(\psi_b - \psi_{true}) \rangle$$

where  $\psi$  is measured separately by detectors  $a$  and  $b$ .

For any 3 detectors one can write :

$$\sigma_a = \langle \cos 2(\psi_a - \psi_{true}) \rangle = \sqrt{\frac{\langle \cos 2(\psi_a - \psi_b) \rangle \langle \cos 2(\psi_a - \psi_c) \rangle}{\langle \cos 2(\psi_b - \psi_c) \rangle}}$$

⇒ Measurement of  $\sigma_{RxnP}$  for the RxnP North and South detectors, both separately and combined, using the BBC North/South and MPC North/South as detectors  $b$  and  $c$ .

## Check on statistical errors

The absolute error on the  $J/\psi v_2$  can be derived from the relative error on the  $\phi - \psi J/\psi$  counts for each bins in  $p_t$  and centrality. The formula is scaled to match our reaction plane resolution :

$$\sigma_N/N = (0,704/\sigma_{\text{RP}}) \frac{\sqrt{\sigma_N^{\text{stat}} + \sigma_N^{\text{syst}}}}{N} \quad (4)$$

This allows to cross-check the point-to-point uncorrelated error on  $v_2$  derived independently from our  $v_2$  measurement macro

## Results using different angles

The number of  $J/\psi$ s going in-plane and out-plane can be calculated with different angle separation :

When changing this angle, the north and arm  $v_2$  agreement of the first 2  $p_T$  bins varies.

# $J/\psi \phi$ resolution

Equation 5 illustrates how this resolution enters the  $v_2$  measurement :

$$\begin{aligned} v_2^{\text{true}} &= \langle \cos 2(\phi_{J/\psi}^{\text{true}} - \phi_{\text{RP}}^{\text{true}}) \rangle \\ &= \langle \cos 2(\phi_{J/\psi}^{\text{meas}} - \phi_{\text{RP}}^{\text{meas}}) \rangle / \left[ \langle \cos 2(\phi_{\text{RP}}^{\text{meas}} - \phi_{\text{RP}}^{\text{true}}) \rangle \langle \cos 2(\phi_{J/\psi}^{\text{meas}} - \phi_{J/\psi}^{\text{true}}) \rangle \right] \\ &= v_2^{\text{meas}} / [\langle \cos 2\Delta\phi_{\text{RP}} \rangle \langle \cos 2\Delta\phi_{J/\psi} \rangle] \end{aligned} \quad (5)$$

$\langle \cos 2\Delta\phi_{\text{RP}} \rangle$  is a correction factor due to the finite resolution of the reaction plane measurement.  $\langle \cos 2\Delta\phi_{J/\psi} \rangle$  is a similar correction, added to account for the finite resolution of the  $J/\psi \phi$  angle measurement. For most of the  $v_2$  measurements so far, this second term has been assumed to be close enough to 1 especially when compared to the reaction-plane correction factor.

In principle, the correction that accounts for the finite resolution of the  $J/\psi \phi$  angle measurement should also be applied to the real-data  $v_2$  measurement, together with the reaction-plane correction. However, it is not possible to measure this resolution directly, nor check that it would match the value obtained with the simulations. It was therefore decided to account for this correction with an additional source of systematic error to the  $v_2$  measurement : only the first  $p_T$  point is affected by this additional uncertainty.